Department of Mechanical Engineering
THE UNIVERSITY OF UTAH

# IRIS-2X

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Sponsor: Trident Sensing

TRIDENT SENSING

## Objective

Tasked by Trident Sensing to design a gimbal for an IR camera that will be used for fire mapping with the following constraints,

- Must fit in a 5-inch diameter tube
- Needs to be 2-axis
- Has to fit a 70-mm camera
- Be able to actuate the camera within 0.1 degrees of accuracy
- Have the ability to stabilize on a given target.

## Design

A 2 degree of freedom spherical mechanism was designed to achieve this objective.

- The roll axis is directly driven with a Dynamixel XL430-W250-T servo motor
  - The roll shaft is made from 316 SS
- The pitch axis is belt driven with a Dynamixel XL430-W250-T servo motor
  - The pitch shaft are AL 6061
  - The use of an M8 bolt allows for tensioning of the belt
- The servos are controlled using a Dynamixel Servo Driver Shield on an Arduino Mega 2560 R3.
- Housings are 3D printed from PLA

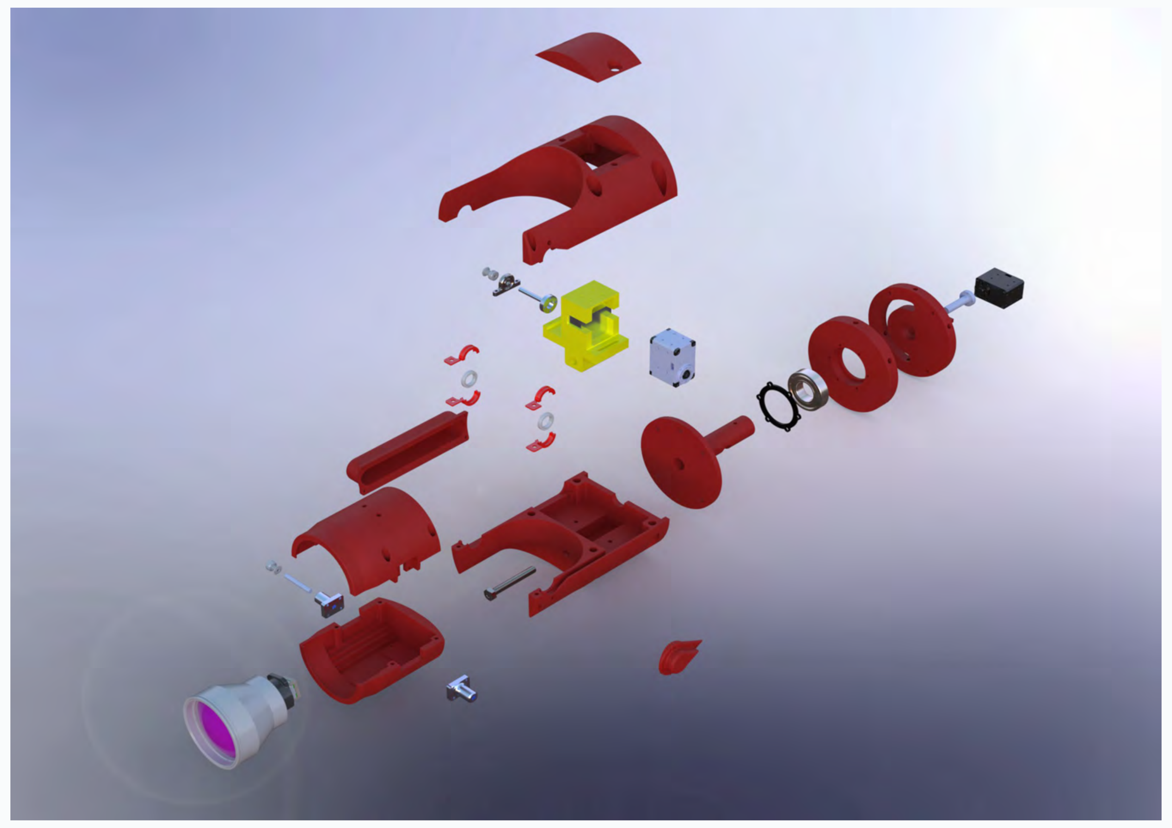


Figure 1: An exploded view of the gimbal.

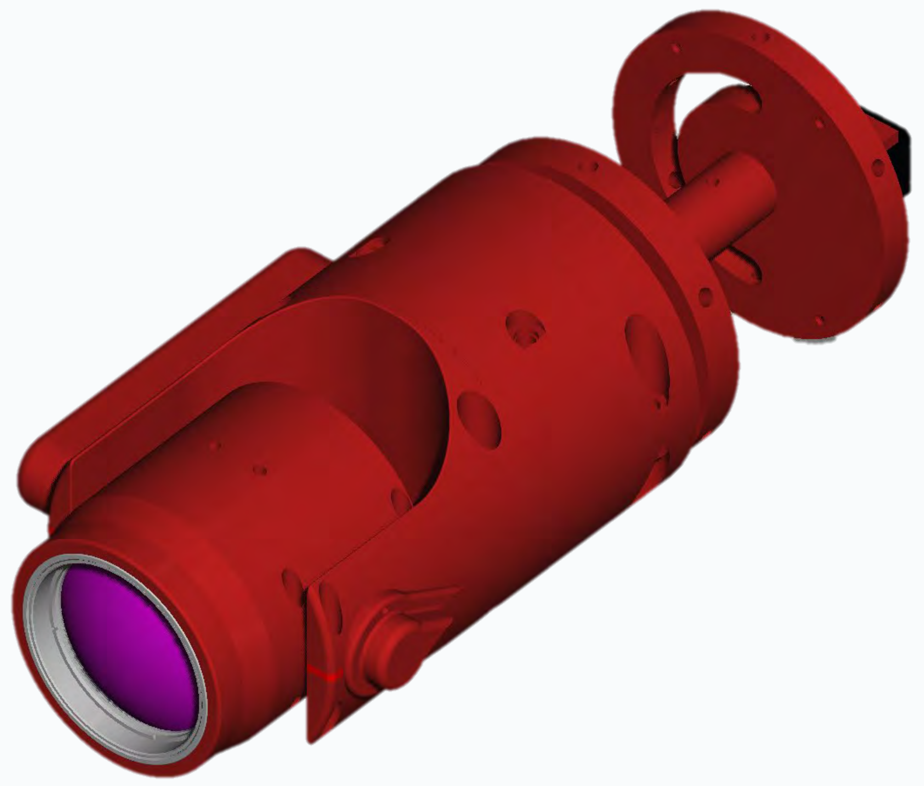
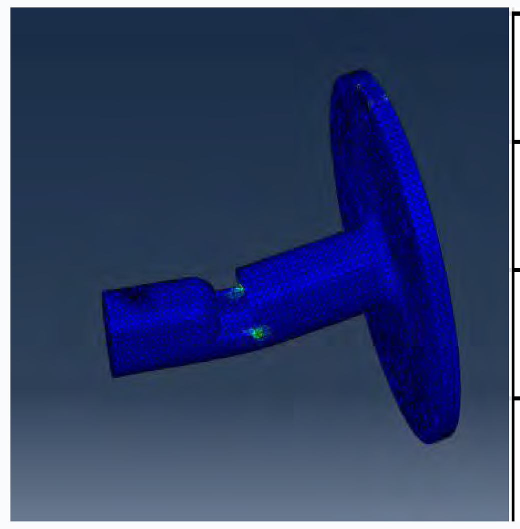


Figure 2: A digital rendering of the gimbal.

## Finite Element Analysis

Load/failure analysis was performed on the roll axle. The results (figure 3 left) show we have a stress concentration on the shaft. Despite this, we attained a safety factor of 9,359. Even if the gimbal is subjected to more extreme loading, the safety factor proves the gimbal shouldn't fail under any conditions it will be exposed to.

Modal analysis was also performed to calculate the natural frequency of the gimbal. The results (figure 3 right) show the first 3 natural frequencies of our gimbal. When comparing this to the aircraft engine's frequency of 47 Hz, it indicates that the shaft is sufficiently rigid to withstand the vibrations caused by the engine.



| Mode | Frequency [Hz] |
|---|---|
| 1 | 100.71 |
| 2 | 116.32 |
| 3 | 198.2 |

Figure 3: The above figure shows results from our loading analysis (left) and the modal analysis (right). A stress concentration can be seen in the loading analysis, where we have a right angle cut out.

## Controller Analysis

A PID controller was used on both roll and pitch motors. A transfer function was found experimentally and gains were tuned using a root locus plot. Requirements for the controller included zero steady state error and no oscillation.

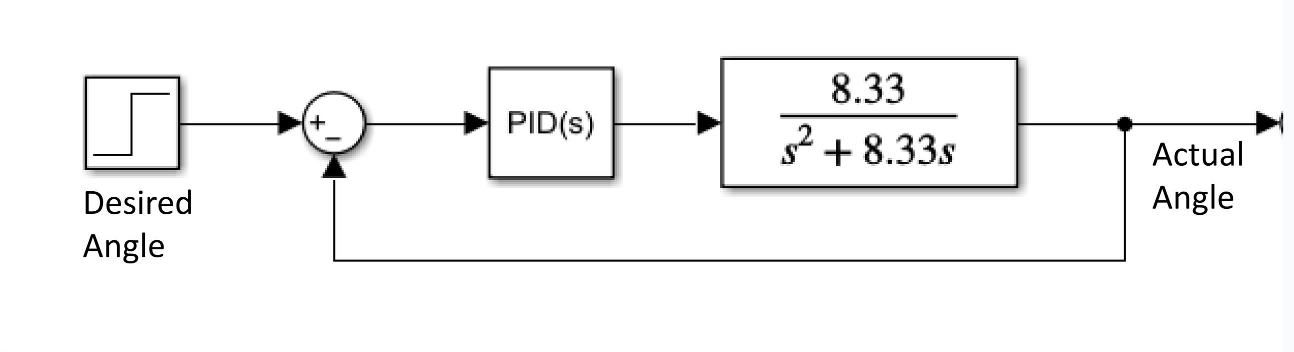



Figure 4: Closed loop transfer function for roll axis

For gimbal stabilization another input was added into the PID loop. The angular velocity was read off an IMU mounted on the base platform and subtracted directly from the PID output.

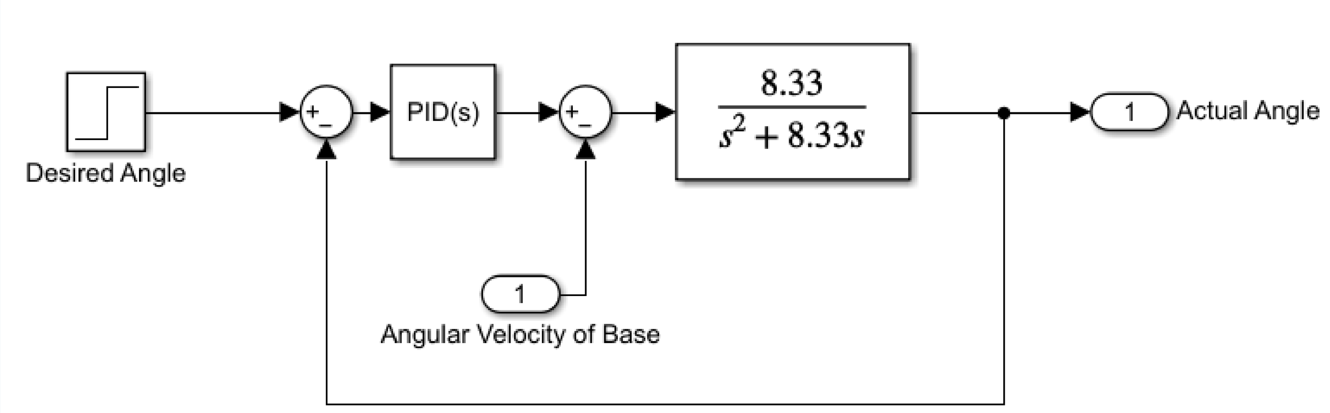



Figure 5: Closed loop transfer function for roll axis with gimbal stabilization

These control systems provided a solid starting point and met the needs for this preliminary design. However, the gimbal's performance is heavily reliant on robust control algorithms and controller design will be ongoing.

## Results

The gimbal was tested by replacing the camera with a laser and commanding the gimbal to point the laser at 12 different targets setup at known distances from the gimbal. Figure 6 shows these results.

The calculated average error in the roll axis is 1.86 deg and the average error in the pitch axis is 0.79 deg.

The average standard deviation in error for the roll axis is 0.3 deg and the average standard deviation in error for the pitch axis is 0.06 deg.

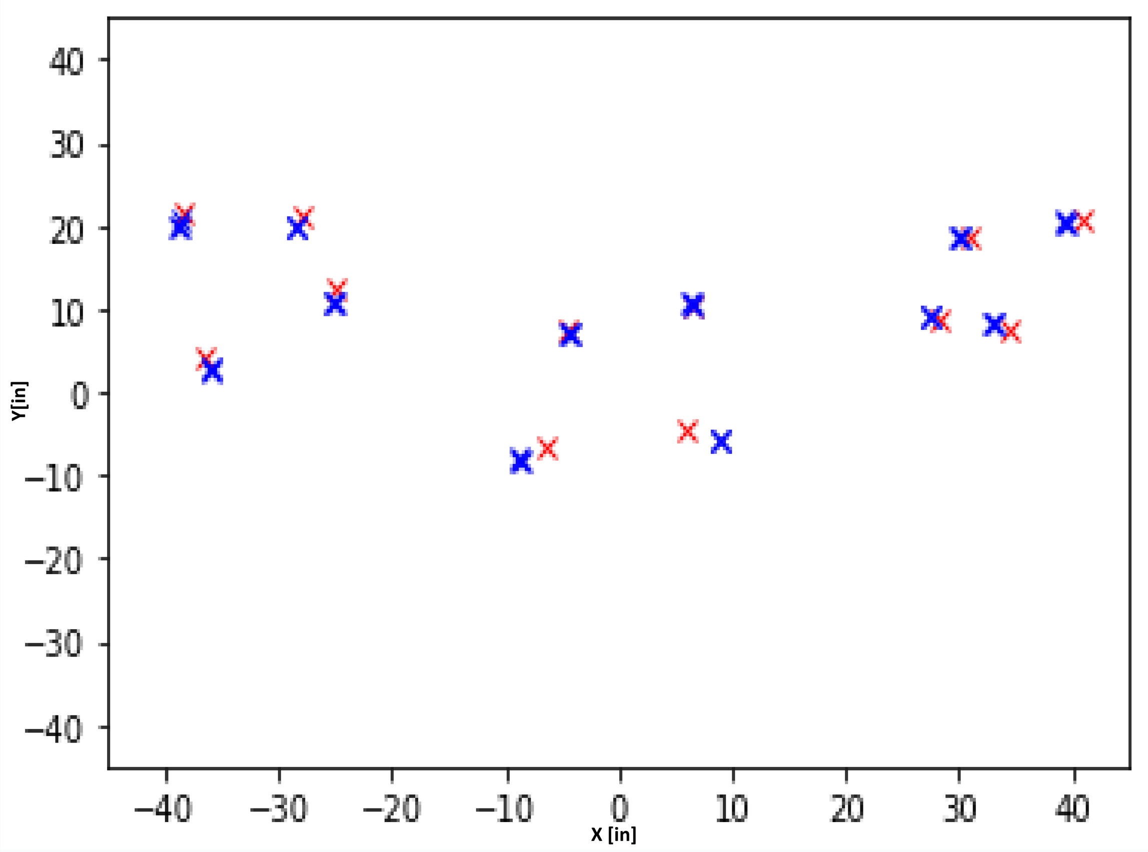



Figure 6: Plot of gimbal test, red "x's" are the targets and blue "x's" are the locations the gimbal hit. The gimbal's home position was aligned with the origin during the test.

## Discussion

The gimbal's increase in precision is a huge step in the right direction for the project. Getting the standard deviation below the user specifications for precision was predicted to be the most challenging part of the project.

The higher errors in accuracy could come from a variety of sources. The likely culprits for this are static friction in the system causing it to exhibit non-linear behavior, error in homing the gimbal to its zero-angle position, error in measurement of the target locations, mechanical backlash in the pitch axis, and error in the concentricity of the laser with the gimbal's roll axis due to the 3d printed mount.While none of these seem to be a large enough source of error by themselves, the combination of the sources could cause the accuracy to be off by the amount measured.